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Brightness Vision in the Deer-Mouse, *Peromyscus maniculatus gracilis*

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A dissertation submitted in partial fulfillment of the requirements for the degree
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BRIGHTNESS VISION IN THE DEER-MOUSE,
PEROMYSCUS MANICULATUS GRACILIS¹

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SIX FIGURES

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INTRODUCTION

Within recent years mice of the genus *Peromyscus*, 'deer-mice' or 'white-footed mice,' have received much attention in the way of genetical, physiological, and distributional studies. Since the action and reaction of animal and environment can only be adequately perceived with the attain-

¹ Contribution from the Zoölogical Laboratory of the University of Michigan.

ment of understanding of the action of the sense organs by which communication between environment and animal is effected, a study of the capabilities of the eyes of *Peromyscus* has seemed a pertinent addition to the knowledge accumulating concerning this rodent. Our knowledge of the nature of vision in the lower animals is at best very meager and the whole field is much in need of thorough, quantitative investigation.

Deer-mice are largely nocturnal in habit. Since to the human eye colors are not perceived as such in dim light, but rather as shades of gray, it has seemed wise to make at first a study of the brightness vision—the ability of the eyes of the animals to distinguish different intensities of light, rather than different wave lengths. The problem with which this paper is concerned, therefore, is the experimental determination of the ability of the deer-mice to distinguish, 1) light from darkness and, 2) between lights differing in intensity, but not in wave length. Since it is also possible that, when similar determinations have been made for other forms, some correlation may be made between visual sensitivity and retinal structure, an account of the histological structure of the retina of the deer-mouse, especially with regard to the nature of the visual-cell layer, is included. It is hoped that extension of the general methods here employed will make possible a series of studies in comparative vision.

The author wishes to take this opportunity to express his gratitude for the continued aid and encouragement given the experimentation by Prof. Alexander G. Ruthven, of the University of Michigan, the helpful advice and criticism given throughout the course of the work by Dr. Lee R. Dice, of the Museum of Zoölogy in that institution, and the interest and aid tendered at all times by Prof. John F. Shepard, of the Department of Psychology in that university, under whose able direction much of the apparatus was planned and most of the experimentation carried on. The writer also wishes to express his appreciation to Mr. William Cristanelli for valuable technical assistance.

As far as known, no previous work on the vision of *Peromyscus* has been attempted. Experiments relating to brightness vision have been performed with the house mouse and the albino rat as subjects, however. The work of Yerkes ('07), on the dancing mouse, of Waugh ('10) and of Keeler ('27), on the house mouse, of the Watsons ('13) and of Spencer ('23), on the albino rat, may be mentioned. With the exception of the work of Yerkes and of Spencer, the results do not bear very directly upon the present problem; the bearing of the results of the latter two investigators is discussed on a later page.

APPARATUS

Aside from the nest boxes of the mice, the experimental apparatus consisted of two main divisions: 1) problem box; 2) light box.

Problem box

The problem box was designed as a modification of the 'Weber's-law apparatus,' constructed by Yerkes ('07, p. 119, fig. 17). As shown in figures 1 and 2, two compartments (*C* and *C'*) side by side were separately illumined from above. The light box by which this illumination was accomplished was so constructed as to allow delicate control of the intensities of illumination, coupled with ready reversal of the positions of the illuminations relative to each other. Electric grids on the floors of the illumined compartments (*C* and *C'*) provided punishment for mistakes.

The main features of the problem box may be learned from figure 1. The outside measurements of the box were $48 \times 15 \times 6$ inches. The box was stained dull black. The doors separating compartments were operated by strings from behind the screen (17, fig. 1). At 6 and 6' a signaling arrangement, operated by the weight of the mouse when emerging from doorways 2 or 2', respectively, is shown. The grids on the floor of compartments *C* and *C'* were stained dull black, thus preventing undesirable reflections. The wiring for the grids and the arrangement by which either the right or the

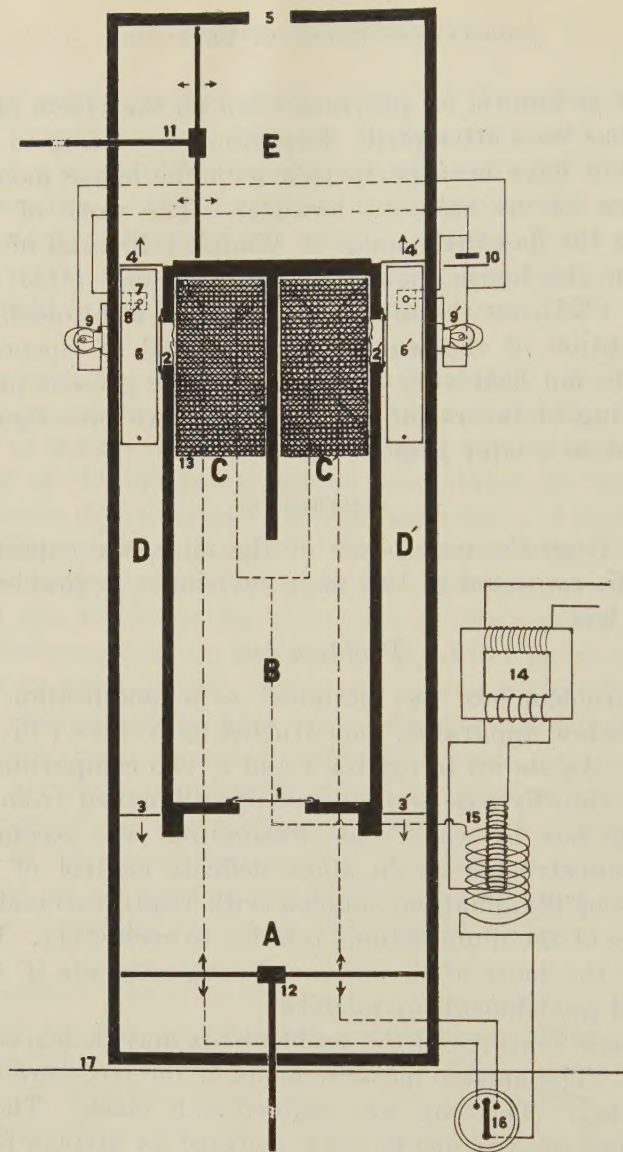


Fig. 1 Floor plan of the problem box, with the wiring of the electric grids and the signal lights. The dashed lines represent the portions of the wires laid under the floor. The letters from *A* to *E* designate the respective compartments. 1, 2, 2', 3, 3', 4, 4', and 5 indicate doors; 6 and 6', pedal switches for the signal lights; 7, copper plate under end of pedal; 8, contact point on under surface of pedal; 9 and 9', signal lights, 2.4-volt bulbs; 10, dry cell; 11 and 12, movable partitions; 13, electric grid for administering shocks; 14, toy transformer connected to alternating city current; 15, small adjustable transformer; 16, two-point switch; 17, opaque curtain.

left grid could be electrified at will are shown. It should be noted that the partition between compartments *C* and *C'* was not full height throughout its length. At its free end it had a height of 1 inch, and from that sloped back to the full height 3 inches from the attached end. The upper portion was cut away after this fashion to permit the mice to see simultaneously both stimulus patches in the 'ceiling' formed by the flashed-opal plates closing the lower end of the light box.

Light box

Construction and operation. The main features of the structure of the light box are shown in figure 2. The box was constructed of quadruple-tinned sheet iron providing mirror-like reflection. The outer surface was stained dull black. From figures 2 and 3 the principles of construction and operation will be seen. By simply turning the pivoted double-faced mirror through an angle of 90° , the relative positions of the lights could be reversed; i.e., the light from the upper lamp house could be shifted from *C* to *C'* and that from the lower lamp house correspondingly from *C'* to *C*, or vice versa. The arrangements for providing even diffusion of light will be noted, as well as the adjustable diaphragms (fig. 4), by means of which the intensities of the light were accurately controlled.

The problem presented to the mice by means of this light box was, therefore, the formation of an association on the basis of difference of brightness of two areas of flashed-opal glass. These areas were 5.5×13 cm. in size and located approximately 5 inches apart above the mice, i.e., in their 'ceiling' (fig. 3). It will be recalled that the mouse eye is located well up on the dorsal surface of the head. From the construction of the apparatus it was possible for a mouse to approach a stimulus patch as closely as $7\frac{1}{2}$ or even 7 inches before stepping upon a shocking grid. Since the partition between compartments *C* and *C'* was slanted down, the mice in making a 'choice' could see both stimulus areas simultaneously at least until they progressed in one compartment or the other as far as the grid.

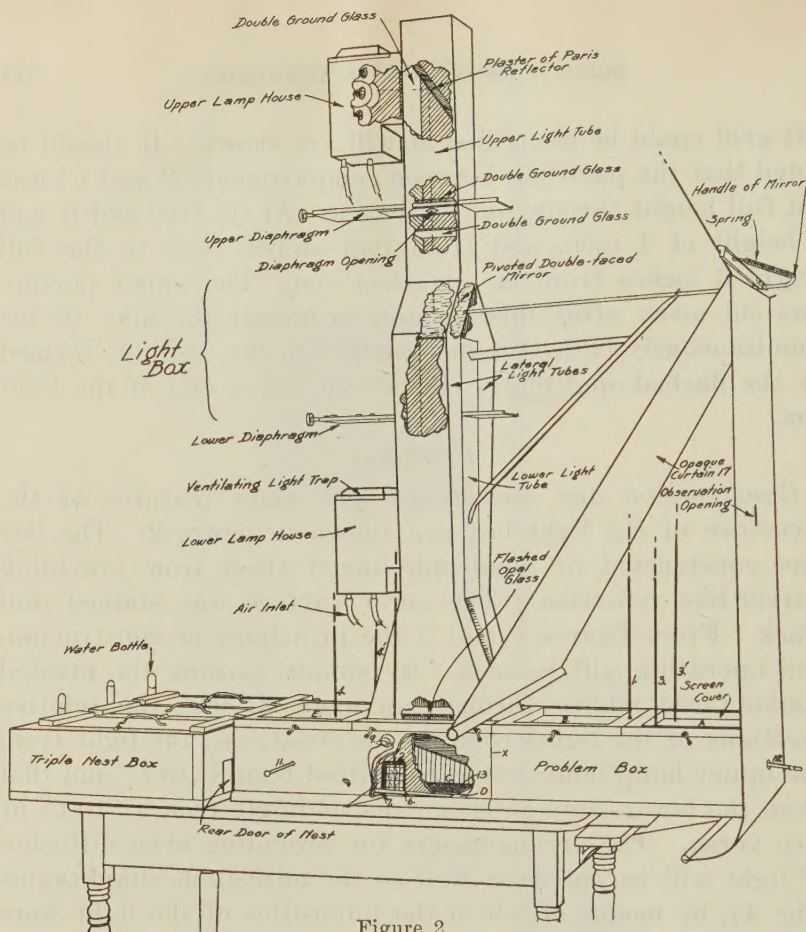


Figure 2

Fig. 2 Perspective view of the visual discrimination apparatus, with portions of the light box and the problem box represented as cut away to reveal interior structures. The dashed line through the light box indicates the path of the light from the upper lamp house when the pivoted mirror was so set as to divert that light to compartment *C* of the problem box. The lower portions of the cords operating the various doors are shown. The sloping upper edge of the partition separating compartments *C* and *C'* will be noted through the portion of the problem box cut away. *X* designates the line at which the right-hand portion of the problem box could be separated from the remainder for photometering of lights. Letters and numbers correspond to those in figure 1.

Fig. 3 Longitudinal section through the light box, with the portion of the problem box beneath the latter. The compartments of the problem box are lettered as in figure 1. The dashed line indicates the course of the light from the upper lamp house when the pivoted mirror was so set that this light was directed to *C*. 13, shocking grid; 18, upper light tube (5 × 5 inch cross-section); 19, lower light tube; 20, lateral light tubes; 21, opening from lower lamp house (closed by double-ground glass plate, 5 × 7 inches); 22, opening from upper lamp house (closed as 21); 23, pivoted, double-faced mirror (4½ × 7 inches); 24 and 26, double-ground glass plates; 25, lower adjustable diaphragm; 27, sheet-metal mask; 28, flashed-opal glass plate.

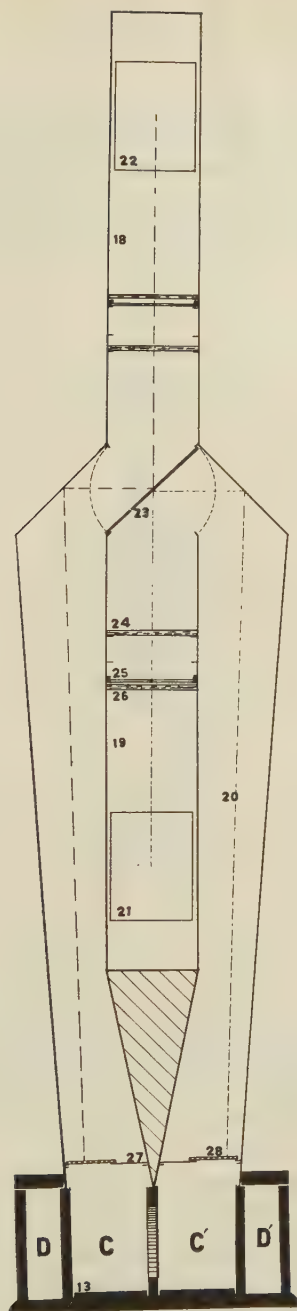


Figure 3

Measurement of light. A Lummer-Brodhun photometer was used to measure light intensity. The portion of the problem box to the right of the line marked X in figure 2 was demountable, space thus being provided for the use of the photometer directly to the light descending through the light box.

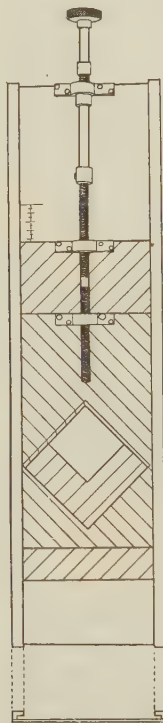


Fig. 4 Adjustable diaphragm. The movable plates are ruled diagonally that their relation may be noted; turning the long screw moved them equally and in opposite directions. A cross-section of the bed or frame is shown at the bottom of the drawing. The diaphragms were of steel.

In practice, light of less intensity than about 0.00085 candle power per square centimeter could hardly be seen, to say nothing of matched, in the photometer. When apertures smaller than 400 mm.² were employed, therefore, it was necessary to calculate the intensities from the readings at that aperture. This calculation was done upon the basis of the

proportion of the areas of apertures. It is realized that this method gives rise to a possible source of error, but its employment in this case was unavoidable and it is not believed that the source of error is large. Tests indicated that the intensities of light passing through the larger apertures were not entirely proportional to the areas of the latter, due to interference by the sides of the light box, but that the smaller the aperture the more accurately could the intensity of light passing through it be thus calculated. Hence there is little doubt but that the intensities for aperture areas of 400 mm.² (20 × 20 mm.) and below were closely proportional to their relative areas.

The unit of brightness employed is candle power per square centimeter (C.cm.²), obtained by dividing the candle power by the area in square centimeters of the stimulus patch of flashed-opal glass. This unit was thought to be more understandable to those interested in this work than would be the 'milli-lambert' of the illuminating engineer.

TECHNIQUE

Experimentation was carried on in a large darkroom on the fourth floor of the Natural Science Building of the University of Michigan. The experiments were conducted in total darkness.

In all cases, aside from preference tests, the mice were trained to go toward the more brightly illumined of two stimulus patches and avoid the more dimly illumined or unillumined one. Punishment for mistakes was the only incentive employed. While the results of some former workers (Hoge and Stocking, '12; Warden and Aylesworth, '27) seem to indicate that a combination of such a reward as food with the punishment is more efficient as an incentive than punishment alone, nevertheless hunger is such an uncertain factor and so difficult of control that no employment of it was attempted. The punishment was administered in the form of a light electric shock, one of such strength as to give an unpleasant tingling to the fingers when the hand was pressed

firmly upon the grid. Experience indicated that a shock of this strength was unpleasant for the mice, but not injurious and also not sufficiently painful to render them unwilling to run in the apparatus.

As a rule, ten trials per day were given each mouse, this number having been found by past workers (Yerkes, '07, and others) to be most efficient both as regards speed of learning and conservation of the experimenter's time. The trials in each series of ten were given in irregular alternation of the relative positions of the two lights being compared. The schedule of alternations was continually varied, the only regulation being that in each series of ten trials the brighter light should be a total of five times on the right-hand side and of five times on the left. In this way the animals were prevented from forming position habits (habits of running regularly to either side regardless of the positions of the lights) and from becoming more familiar with one side of the apparatus than with the other.

No detailed account of the technique need be given. Compartment *A* (fig. 1) served as the starting box. After each trial the animal returned to the latter. Throughout most of the tests the door (*2* or *2'*) on the side dimly illumined and having its grid electrified for a given trial was closed, necessitating retracing of steps by the subject so as to exit on the correct side. Doors *4* and *4'* were closed during trials, so that the mice could not enter compartment *E*, which served only as an antechamber for the introduction of mice from their nests through doorway *5*.

Every effort was made to prevent the mice from relying upon any other cue than vision in the apparatus. The doors were operated as quietly as possible, and doors *2* and *2'* were constructed of very coarse mesh of fine wire and hidden from view by black-cloth curtains. On one individual the influence of varying the manner of opening doors *2* and *2'* was tested, with entirely negative results. During some of the earlier tests both doors were regularly opened at each trial. Testing of the electrified grids by vibrissae or other means was

carefully guarded against. A trial was counted as wrong if the subject came in contact with the electrified grid.

Objection is sometimes made to a movable partition such as that in compartment *A* (fig. 1), the reason being that the observer might subconsciously direct the mouse toward one side or the other thereby. Apparatus has sometimes been constructed in such a manner that this objection has been valid. In the present apparatus, however, regardless of which side was correct in a given trial, the movable partition always simply directed the mouse to a point midway between the lights to be discriminated, i.e., to doorway 1. If any driving were necessary to urge the mouse from compartment *B*, unpleasant formalin odors accomplished it. Small glass dishes containing weak formalin solution were placed in the corners of *B* adjacent to doorway no. 1. Electric shock has sometimes been used to drive animals from the starting boxes of apparatus as well as to punish mistakes. The association which must be built up in the animal's mind would seem to be simplified if shock were connected with but the one aspect of the experimental situation.

The most convincing evidence that the mice were in reality not relying for cues upon any factors in the manipulation of the apparatus, but rather upon the differences of light intensity, is derived from the following fact. The manipulation of the apparatus remained constant regardless of light intensities; the latter alone varied. As is shown further on, the mice in every case reached a point at which they were no longer able to avoid the electric shock successfully, i.e., a point at which they could no longer distinguish between the lights. Were they dependent upon some cue from the manipulation of the apparatus, such a point would not have been reached.

Heat, a complicating factor in many experiments employing light, was by the construction of the light box entirely eliminated from the experimental situation.

EXPERIMENTAL ANIMALS

The experimental animals were six males of the species of deer-mouse inhabiting the deep forest regions of northern Michigan, *Peromyscus maniculatus gracilis* LeConte. They formed part of the stock kept for experimental purposes by Dr. L. R. Dice, of the University of Michigan Museum. They were known by their pedigree numbers, which were: 27, 290, 291, 299, 300, 302.

The mice were born and reared in cages. The wild ancestors of all six were trapped at Elmira, Michigan, on September 2, 1923. The parents of no. 27 were two of these wild mice, this mouse having been born in December of 1924. The other five mice were of the second cage-bred generation and had common parentage. Nos. 290 and 291 were born in a litter of about March 10, 1926, while nos. 299, 300, and 302 were born in a litter of about April 21st of the same year. The parents of no. 27 were also the maternal grandparents of the other five individuals. That a fairly homogeneous stock was used is consequently evident, all six being eventually derived from four wild mice trapped at the same time in the same locality. At the conclusion of experimentation, no. 27 was approximately two and one-third years of age and the other five mice were slightly over one year old. The latter individuals attained their mature pelage in the fall of 1926.

PREFERENCE TESTS

The six experimental animals were given preference tests at the outset of the training, in order to ascertain whether any preference was present to go to an illumined or to an unillumined compartment. In these tests no shocks were administered and both doors 2 and 2' were opened at each trial. At this time compartments *C* and *C'* were entirely separated; the partition between them was full height throughout its length. A partition also extended across the ends of the compartments separating them from compartment *B*; communication from the latter to *C* or to *C'* was effected by doorways 3 inches square. The stimulus patches

were not masked down to the size subsequently employed, but consisted of double-ground glass plates forming the entire ceilings of *C* and *C'*. The intensity values given in the table

TABLE 1
Preference tests

DATE	27	DATE	290		291		299	300	302
1925	Br. Dk.	1926	Vari.	Br. Dk.	Vari.	Br. Dk.	Br. Dk.	Br. Dk.	Br. Dk.
3/10	4-6p	6/18	4476.	9-1	4476.	7-3p			
3/11	4-6p	6/19			4476.	8-2			
3/14	4-6	6/21	4476.	10-0	4476.	4-6a			
3/17	6-4	6/22	4476.	10-0	4476.	2-8			
3/18	3-7	6/23	4476.	9-1	4476.	6-4a			
3/19	5-5	6/24	4476.	10-0	4476.	8-2p			
3/20	4-6	6/25	4476.	10-0	4476.	6-4p			
3/26	3-7	6/26	4476.	10-0	4476.	8-2	9-1	8-2	10-0
3/27	5-5p	6/28	11882.	10-0	4476.	7-3p	7-3p	9-1	10-0
3/30	7-13p	6/29	11882. 194.	10-0	4476.	5-5p	9-1	9-1	10-0
3/31	3-7	6/30	11882. 840.7	9-1	4476.	9-1	10-0	10-0	10-0
4/1	4-6p	7/1	11882. 1844.	7-3	4476.	6-4a	10-0	10-0	10-0
4/2	3-7	7/2	11882. 1844.	7-3	1844.	3-7p	9-1	9-1	10-0 ¹
4/3	4-6	7/3	11882. 4476.	5-5p	1844.	5-5a	10-0	10-0	10-0
		7/5	11882. 1844.	7-3p					
		7/6	11882. 1844.	7-3a	11882. 1844.			9-6	7-3p

Vari., intensities of variable light in candle power per $\text{cm}^2 \times 10^{-6}$, at 110 volts. Light against darkness except where two intensity values are given together indicating two lights. *Br.*, number of times the illumined compartment was chosen. *Dk.*, number of times the unillumined or more dimly illumined compartment was chosen. *p*, formation of position habit. *a*, formation of habit of regular right-left alternation. Nos. 291, 299, 300, 302 have a common 'Vari.' column.

¹ First five tests, Vari.: 4476; second five, Vari.: 1844.

are consequently those of the brighter area of each which alone constituted the stimulus patch in later tests.

It will be noted from table 1 that nos. 290, 299, 300, and 302 showed very decided preference for the illumined as opposed to the unillumined compartment. Except in one series in

which two lights were used, no. 302 chose the illumined compartment every trial for eight series of ten trials. The records of no. 291, on the other hand, indicate little if any preference. Similarly, no. 27 indicated no preference or at most very little, and that tending toward the unillumined compartment. The light used with this animal was much stronger than that used with the others, and the results were doubtless not comparable. This light was unphotometered. No. 290 was given several series of preference tests in which two lights were used. The brightest illumination of which the apparatus was capable was used, a far dimmer light being opposed to it. The intensity of the dimmer light was gradually increased from day to day. As the table indicates, the mouse continued to go consistently to the brighter light until the intensity of the dimmer reached 1844×10^{-6} C. cm.², the brighter being $11,882 \times 10^{-6}$ C. cm.² Subsequently, only a slight preference for the brighter compartment was manifested.

DISCRIMINATION FROM DARKNESS

Following the preference tests, definite training was begun. Since the determination of rate of learning was not a part of the problem at hand, advantage was taken of any preference the mice might have to go to an illumined compartment by training them to avoid the dark compartment, as described above. Compartments *C* and *C'* and the stimulus patches had still the form described above under Preference Tests. Since the brighter area of the stimulus patch must have been the portion controlling discrimination, the more dimly illumined margin, later masked off, may be neglected.

The data for the tests are given in table 2, arranged as was table 1, except that 'R' (right) and 'W' (wrong) are substituted as captions for 'Br' and 'Dk,' respectively. Light intensities are again expressed in terms of candle power per square centimeter $\times 10^{-6}$. In subsequent discussions the ' $\times 10^{-6}$ C. cm.²' will, for the sake of brevity, be simply understood as following the numbers expressive of light intensities.

TABLE 2
Discrimination from darkness

DATE	27		290		291		299		300		302	
1926	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
7/7	1844.	10-0	1844.	8-2	1844.	4-6	1844.	10-0	1844.	10-0	1844.	9-1
7/8	840.7	8-2	840.7	9-1	1844.	9-1	840.7	10-0	840.7	10-0	840.7	8-2
7/9	840.7	9-1	840.7	8-2	840.7	5-5a	840.7	10-0	840.7	5-5	840.7	8-2
7/10	840.7	10-0	840.7	8-2	840.7	8-2	840.7	10-0	840.7	7-3	840.7	9-1
7/12	840.7	10-0	840.7	10-0	840.7	8-2	840.7	10-0	840.7	8-2	840.7	7-3
7/13	460.6	10-0	460.6	9-1	840.7	9-1	460.6	10-0	840.7	10-0	840.7	10-0
7/14	194.	10-0	460.6	10-0	840.7	7-3	194.	10-0	460.6	6-4a	460.6	8-2
7/15	40.8	8-2	194.	10-0	840.7	9-1	40.8	4-1	460.6	10-0	460.6	9-1
7/16	40.8	7-3p	194.	10-0	840.7	9-1	40.8	10-0	194.	9-1	460.6	9-1
7/17	40.8	7-3	40.8	9-1	840.7	9-1	40.8	9-1	194.	9-1	460.6	10-0
7/19	40.8	7-3	40.8	9-1	840.7	9-1	40.8	9-1	194.	9-1	194.	9-1
7/20	40.8	5-5	40.8	10-0	840.7	9-1	40.8	8-2	194.	9-1	194.	10-0
7/21	194.	10-0	17.	7-3p	840.7	10-0	40.8	10-0	194.	10-0	40.8	10-0
7/22	40.8	8-2	17.	6-4	460.6	10-0	17.	8-2	40.8	7-3	17.	8-2
7/23	40.8	5-5	17.	9-1	194.	10-0	17.	10-0	40.8	9-1	17.	8-2
7/24	194.	10-0	17.	10-0	40.8	10-0	8.9	9-1	40.8	9-1	17.	10-0
7/26	136.1	9-1	8.9	7-3p	17.	7-3	8.9	9-1	40.8	9-1	8.9	9-1
7/27	136.1	9-1	8.9	5-5p	17.	9-1	8.9	9-1	40.8	8-2	8.9	5-5p
7/29	136.1	7-3	8.9	5-5p	17.	8-2	8.9	10-0	40.8	8-2	8.9	5-5p
7/30	136.1	10-0	17.	7-3	17.	10-0	3.4	4-6p	40.8	9-1	17.	9-1
7/31	103.2	6-4	17.	6-4p	8.9	8-2	8.9	5-5p	40.8	8-2	17.	10-0
8/2	103.2	10-0	17.	8-2	8.9	10-0	8.9; 17	7-3	40.8	9-1	17; 8.9	10-0
8/3	74.8	9-1	17.	10-0	8.9; 3.4	5-2	17.	7-3p	40.8	8-2		
8/4	74.8	9-1	17.	7-3	8.9	7-3	17.	6-4p	40.8	10-0	8.9	10-0
8/5	74.8	10-0	17.	8-2	8.9	4-6p	17.	13-3	17.	9-1	8.9	9-1
8/6	51.	8-2	17.	8-2	17.	9-1	17.	9-1	17.	9-1	8.9	10-0
8/7	51.	7-3p	17.	7-3	17.	8-2	17.	6-4p	17.	8-2	8.9	7-3a
8/9	51.	8-2	17.	10-0	17.	8-2	17.	9-1	17.	10-0	8.9	9-1
8/10	51.	5-5p	8.9	5-5p	17.	8-2	17.	6-4p	8.9	9-1	8.9	6-4p
8/11	51.	10-0	17.	10-0	17.	9-1	40.8	6-4p	8.9	10-0 ¹	8.9	10-0 ¹
8/11					8.9	9-1			3.4	10-0 ¹	3.4	9-1 ¹
8/11					3.4	10-0			1.13	5-5 ¹	3.4	10-0 ¹
8/11					1.13	8-2					1.13	5-5 ¹
8/11					1.13	5-5p					1.13	9-1 ¹
8/11											closed	3-7p ¹
10/1	194.	10-0	194.	10-0	194.	10-0	40.8	10-0	40.8	10-0	40.8	10-0
10/2	40.8	8-2	40.8	10-0	40.8	10-0	17.	10-0	17.	10-0	17.	10-0
10/4	40.8	5-5p	17.	6-4p	17.	9-1	8.9	6-4	8.9	9-1	8.9	6-4p
10/5	51.	5-5p	17.	9-1	17.	9-1	8.9	9-1			17.	10-0
10/5	103.2	6-4p									8.9	10-0
10/5											3.4	8-2
10/6	103.2	10-0	17.	10-0					8.9	10-0	8.9	8-2
10/6	40.8	9-1	8.9	9-1					3.4	10-0	8.9	10-0
10/6									1.13	10-0		
10/6									1.13	7-3		
10/7	40.8	6-4p			17.	7-3	8.9	9-1			3.4	8-2
10/7	40.8	5-5p					8.9	9-1				
10/8			8.9	10-0	17.	10-0			8.9; 3.4	9-1		
10/8			3.4								8.9	10-0 ²
10/8			1.13	6-4p	8.9	8-2 ²	8.9	8-2 ²	3.4	10-0	3.4	10-0 ²
10/8					3.4	9-1 ²	3.4	9-1 ²	1.13	9-1	1.13	6-4 ²
10/8					1.13	7-3 ²	1.13	6-4 ²	closed	3-7p	1.13	9-1 ²
10/8					1.13	8-2 ²	1.13	6-4p ²			closed	0-10 ²
					closed	4-6 ²					closed	6-4p ²

Vari., as in table 1; R., right; W., wrong. ¹ Given 8/12. ² Given 10/9.

Training was begun with the variable light at an intensity of 1844 ($\times 10^{-6}$ C. cm.²). As soon as a mouse made a satisfactory record of discrimination at one intensity, the latter was diminished. In this manner the intensity was gradually reduced step by step as the animals proved their ability to discriminate. Progression was by no means continuous, however; at times with each mouse the association between avoiding the shock and staying out of the unilluminated compartment seemed to break down, and increase in the intensity of the light was necessary. Further drilling would then re-establish the association, and the gradual reduction of intensity could continue. Great individual differences in rate of learning were clearly manifested.

Good records were made at the outset by the majority of the mice. This fact can no doubt be accounted for by the preference which most of them had already shown of seeking the illuminated compartment. No. 27 had already received over 600 training tests in the apparatus and had formed a good discrimination habit. Since a cruder light box with unmeasured light intensities was used, the data for these tests are not included in the table. By August 11th, the intensity of the light employed with nos. 291, 300, and 302 had been reduced to a value of 17 or below, which may be contrasted with the intensity of 1844 with which the tests began on the 7th of the previous month. As in succeeding tests, the method of giving several series in succession was employed when a mouse seemed to have about reached his discriminative limit. By this means it was hoped to bring out the utmost of his ability. The sixty trials given no. 302 on August 12th may be cited as an example of the working of this method, culminating in a series in which the diaphragm was entirely closed as a check against other possible cues than the light.

On August 11th, no. 300 made a perfect record with a light intensity of 3.4, but failed at an intensity of 1.13. No. 291 made a perfect record with the former intensity and but two mistakes in ten trials at the latter. A second series at 1.13 resulted in a perfect chance record, however. After an

interim, work was resumed on October 1st. After a period of retraining, nos. 291, 300, and 302 were again able to make good records at an intensity of 1.13. Nos. 290 and 299 were unable to do so, though they made satisfactory records with the intensity of 3.4. No. 27 failed to discriminate at intensities much higher.

The results indicate, therefore, that, judging by the records of the mice showing the most ability, the limen of discrimination of light from darkness lies for the deer-mice slightly under an intensity of 1.13 ($\times 10^{-6}$ C. cm.²).

Some statement should be made as to the criterion taken as indicative of discrimination. Following the precedence of previous workers with discrimination problems (Yerkes, '07, p. 123; Spencer, '23, pp. 401-402), records 75 per cent to 80 per cent correct have been taken as the dividing line between evidence of discrimination and lack of evidence of it. More specifically, records for ten trials in which all trials are correct, those in which nine trials are correct, and those in which eight trials are correct are considered indicative of discrimination. The question will suggest itself as to how frequently such records might result purely as a matter of chance. By the laws of chance, all discrimination being eliminated, perfect series of ten trials each might be expected to be made once in the course of 1024 series. Similarly, by the laws of chance, a record of nine correct runs or better in a series of ten trials would be expected once in the course of about ninety-three series. Finally, as a matter of pure chance, series of ten trials each in which eight or more trials were correct would be expected about once in eighteen series. While it is evident, therefore, that occasional 10-to-0, 9-to-1, and especially 8-to-2 records may result purely from chance when the animal is unable to discriminate, it is equally evident that such records recurring in succession time after time as indicated in the tables are not attributable to chance.

DISCRIMINATION FROM A STANDARD INTENSITY OF 40.84×10^{-6} C. cm.²

Training with two lights immediately succeeded the tests on the threshold from darkness. Beginning with these tests, the 'ceilings' of compartments *C* and *C'* were masked as previously described so as to exclude all light save that through the uniformly illuminated area 5.5×13 cm. in size. The variable light was the brighter of the two; at the outset it had a considerably greater intensity than the standard. Since the incentive (punishment) was always connected with the dimmer light, the association required of the animal was evidently simplified, if absolute intensity has any importance, by having the light with which the incentive was connected remain constant. In advance of complete test, it should always be assumed that absolute intensity may be an appreciable factor. The work of Gayton ('27) seems to indicate that absolute intensity is of subordinate importance to relative in discrimination between two lights by white rats. The dimmer light became the standard toward which the brighter variable light was gradually reduced, therefore, with the result that in a given set of tests the animals always received the shock with light of the same intensity. This point of technique has not always been observed in discrimination problems.

As the first part of table 3 indicates, weeks of tests were given without any very definite sign of improvement in discrimination. The formation of a habit of discrimination between the intensities of two lights might be expected to present a more difficult problem than that of a habit of discrimination of light from darkness. Yet such an anticipation would hardly foresee the result obtained until November 19th. The line drawn across the table following that date indicates the point at which compartments *C* and *C'* were modified as described above (p. 371) from the form described under Preference Tests. The partition separating these compartments from *B* (fig. 1) was removed so that they opened broadly into the latter, while the partition between them was sloped down as indicated previously. These modifications

were made on the probability that the reason the mice found such difficulty in discrimination was because of the fact that they were unable to compare the stimulus patches simultaneously, but were compelled to look at them in succession. In fact, in many cases they did not pass from door to door so as to compare the intensities, but seemed to react by approach to the first light they saw, doubtless in accord with the light vs. darkness association they had already acquired. There would, of course, be more chance of their seeing the more brightly illumined compartment first as against the darker or unillumined one; thus, the majority of the reactions would be right, as the records show that they were. The modifications enabled the animals to see both stimulus patches at once until they progressed in *C* or *C'* as far as the shocking grids. With the modification, the association to be formed became one of avoidance of the darker of a visual pair, and this was gradually established. Before the modification, what was demanded was avoidance of an absolute brightness, or of one which would give the impression dark with an indefinite time interval between stimuli. The latter association was evidently very difficult, at least with the stimulus differences used and with an effective response to a lighted area as against darkness already established. The result obtained is suggestive of Koehler's experiments ('18). That the modifications were in reality largely instrumental in making discrimination possible is amply attested by the results of the succeeding tests.

The question may arise as to the possible effect of the inability of the mice to see both stimulus patches at once upon the tests which preceded the modifications described. Since in the latter tests, however, the other parts of the problem box shared the 'standard intensity,' i.e., were likewise in total darkness, the habit required of the mice was simply that of going toward any perceptible light whatsoever and inability to simultaneously see the negative (dark) stimulus patch was consequently not detrimental.

TABLE 3

Discrimination from a standard intensity of 40.84×10^{-6} C. cm.²

DATE	27		290		291		299		300		302	
1926	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
10/11	198.6	6-4p	198.6	7-3a	198.6	6-4	198.6	8-2	198.6	9-1	198.6	6-4p
10/12	198.6	7-3	198.6	7-3p	198.6	7-3a	198.6	3-7	470.4	4-6p	198.6	6-4a
10/13	470.4	10-0	470.4	8-2	470.4	7-3	470.4	6-4p	470.4	6-4p	470.4	3-7p
10/14	198.6	10-0	470.4	9-1	470.4	9-1	470.4	4-6p	470.4	7-3	470.4	5-5
10/15	117.	7-3	470.4	10-0	470.4	7-3	470.4	5-5	470.4	6-4	470.4	3-7
10/16	117.	5-5p	198.6	8-2	470.4	6-4p	470.4	7-3	470.4	10-0	470.4	3-7
10/21	198.6	5-5p	198.6	9-1	470.4	8-2	470.4	7-3p	198.6	6-4p	470.4	5-5p
10/23	470.4	9-1	198.6	8-2	470.4	6-4	470.4	9-1	198.6	8-2	470.4	7-3a
10/25	198.6	8-2	198.6	10-0	470.4	7-3a	470.4	8-2	198.6	7-3a	470.4	7-3a
10/26	198.6	7-3p	117.	8-2	470.4	8-2	470.4	5-5	198.6	7-3	470.4	5-5
10/27	198.6	6-4p	117.	5-5p	470.4	6-4	470.4	5-5a	198.6	6-4	470.4	8-2
10/28	198.6	5-5p	198.6	5-5p	470.4	6-4	470.4	6-4	198.6	3-7p	470.4	6-4p
10/29	470.4	10-0	470.4	5-5p	470.4	10-0	470.4	5-5a	470.4	3-7	470.4	10-0
10/30	288.5	8-2	470.4	10-0	288.5	8-2	470.4	5-5	470.4	8-2	288.5	8-2
11/1	288.5	5-5	288.5	9-1	288.5	7-3a	470.4	6-4a	470.4	9-1	288.5	6-4
11/2	288.5	9-1	288.5	10-0	288.5	6-4p	470.4	6-4p	470.4	9-1	288.5	7-3
11/3	198.6	5-5p	198.6	10-0	288.5	8-2	470.4	8-2	288.5	8-2	288.5	7-3
11/4	288.5	6-4p	163.5	9-1	288.5	6-4	470.4	7-3	288.5	9-1	288.5	4-6p
11/5	288.5	6-4p	163.5	8-2	288.5	7-3	470.4	9-1	198.6	4-6	288.5	9-1
11/6	288.5	8-2	163.5	9-1	288.5	7-3a	470.4	9-1	198.6	8-2	288.5	8-2
11/8	288.5	7-3	117.	7-3	288.5	7-3	288.5	8-2	198.6	5-5p	288.5	9-1
11/9	288.5	8-2	117.	6-4	288.5	8-2	288.5	8-2	198.6	5-5	198.6	7-3
11/10	288.5	8-2	117.	8-2	288.5	8-2	288.5	6-4p			198.6	8-2
11/11	288.5	7-3	117.	7-3	288.5	7-3	288.5	7-3p	198.6	9-1	198.6	6-4
11/12	288.5	5-5	117.	6-4p	288.5	7-3p	288.5	6-4	198.6	7-3	198.6	6-4p
11/13	857.1	7-3	198.6	9-1	857.1	10-0	288.5	7-3	857.1	7-3a	857.1	9-1
11/15	857.1	6-4p	198.6	10-0	857.1	6-4	288.5	9-1	857.1	8-2	857.1	8-2
11/17	857.1	6-4p	117.	7-3	857.1	9-1	288.5	6-4	857.1	8-2	857.1	10-0
11/18	857.1	8-2	163.5	10-0	857.1	8-2	288.5	7-3p	857.1	7-3p	857.1	6-4p
11/19	857.1	8-2	117.	7-3	857.1	10-0	288.5	4-6	857.1	10-0		
11/22	1880.	7-3	1880.	4-6p	1880.	7-3	1880.	9-1	1880.	9-1	1880.	8-2
11/24											1880.	6-4
11/25	1880.	5-5	1880.	3-7	1880.	7-3	1880.	10-0	1880.	7-3	1880.	10-0
11/26	1880.	6-4	1880.	6-4p	1880.	9-1	1880.	6-4p	1880.	8-2	1880.	8-2
11/27	1880.	10-0	1880.	8-2	1880.	10-0	1880.	9-1	1880.	8-2	1880.	10-0
11/29			1880.	10-0								
11/30	1880.	7-3	1880.	6-4	1880.	10-0	1880.	8-2	1880.	9-1	1880.	9-1
12/1	1880.	9-1	1880.	8-2	1880.	9-1	1880.	9-1	1880.	8-2	1880.	8-2
12/2	1880.	9-1	1880.	9-1	1880.	10-0	1880.	10-0	1880.	10-0	1880.	10-0
12/3	1880.	7-3	1880.	10-0	1880.	10-0	1880.	7-3	1880.	10-0	1880.	10-0
12/4	1880.	10-0	1880.	9-1	1880.	10-0	1880.	7-3	1880.	8-2	1880.	10-0
12/6	1880.	4-6	1880.	10-0	857.1	9-1	1880.	8-2	1880.	9-1	857.1	10-0
12/7	1880.	7-3	1880.	9-1	857.1	9-1	1880.	9-1	1880.	10-0	470.4	8-2
12/8	1880.	8-2	1880.	9-1	857.1	10-0	1880.	9-1	1880.	10-0	470.4	10-0
12/9	1880.	10-0	1880.	10-0	470.4	10-0	1880.	10-0	1880.	10-0	198.6	10-0
12/10	1880.	8-2	1880.	9-1	198.6	10-0	1880.	9-1	1880.	10-0	117.	8-2
12/11	1880.	9-1	1880.	8-2	117.	10-0	1880.	8-2	857.1	10-0	117.	6-4p
12/13	1880.	9-1	1880.	9-1	87.8	10-0	1880.	9-1	470.4	10-0	198.6	6-4a
12/14	1880.	8-2	1880.	8-2	62.7	7-3	1880.	9-1	198.6	8-2	470.4	8-2
12/15	1880.	8-2	1880.	10-0	62.7	8-2	1880.	9-1	198.6	9-1	470.4	10-0
12/16	1880.	9-1	1880.	10-0	62.7	8-2	1880.	10-0	198.6	10-0	117.	8-2

TABLE 3—Continued

DATE	27		290		291		299		300		302	
	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
1927												
1/12	1880.	10-0	1880.	8-2	1880.	10-0	1880.	9-1	1880.	10-0	1880.	8-2
1/13	857.1	9-1	1880.	8-2	470.4	9-1	1880.	9-1	470.4	10-0	1880.	9-1
1/14	857.1	10-0	1880.	10-0	470.4	9-1	1880.	9-1	198.6	10-0	1880.	9-1
1/15	470.4	9-1	857.1	10-0	470.4	10-0	1880.	10-0	117.	7-3	1880.	10-0
1/17	470.4	9-1	470.4	10-0	198.6	9-1	857.1	10-0	117.	6-4	857.1	10-0
1/18	470.4	8-2	198.6	5-5p	198.6	9-1	470.4	9-1	198.6	9-1	470.4	9-1
1/19	470.4	9-1	470.4	10-0	198.6	8-2	470.4	9-1	198.6	7-3a	470.4	10-0
1/20	470.4	9-1	198.6	6-4p	198.6	9-1	470.4	10-0	470.4	8-2	198.6	9-1
1/21	470.4	9-1	198.6	9-1	198.6	10-0	198.6	6-4	470.4	9-1	198.6	10-0
1/21									198.6	8-2		
1/22	198.6	5-5p	198.6	7-3	117.	5-5p	198.6	7-3	198.6	8-2	117.	9-1
1/24	470.4	9-1	198.6	8-2	117.	8-2	198.6	8-2	198.6	8-2	117.	8-2
1/25	288.5	7-3	198.6	3-7	117.	9-1	198.6	7-3	198.6	6-4	117.	9-1
1/26	288.5	7-3	288.5	10-0	117.	7-3	288.5	6-4p	288.5	7-3	117.	9-1
1/26			198.6	8-2								
1/28	470.4	9-1	198.6	8-2	117.	7-3	470.4	9-1 ¹	288.5	7-3a ¹	87.8	6-4p
1/28	288.5	8-2	117.	6-4p	198.6	6-4	198.6	7-3p ¹	470.4	10-0 ¹	117.	10-0
1/28	198.6	8-2					288.5	7-3p ¹	198.6	9-1 ¹	87.8	8-2
1/28									117.	8-2 ¹		
2/1	288.5	6-4	288.5	9-1	288.5	9-1 ²			198.6	10-0		
2/1	470.4	10-0	198.6	10-0	198.6	10-0 ²			117.	7-3		
2/1	198.6	4-6p	117.	9-1	117.	9-1 ²			117.	8-2		
2/1			87.8	7-3	87.8	8-2 ²			87.8	9-1		
2/1			87.8	6-4	62.7	6-4p ²			62.7	4-6p		
2/2							288.5	8-2	117.	10-0	117.	10-0
2/2							198.6	8-2	87.8	5-5	87.8	7-3
2/2							117.	7-3p			87.8	8-2
2/2							87.8	5-5			62.7	6-4p

¹ Given 1/29. ² Given 1/31.

Following the modification of the problem box, training was begun with the variable light at a relatively strong intensity. As table 3 indicates, the variable was held at this intensity for each mouse until the discrimination habit seemed thoroughly fixed. It will be noted that the lowest intensity at which the mice made records of 8 to 2 or above was 87.8. No. 291 offered an exception to this fact. On December 14th, this mouse made a 7-to-3 record with the intensity at 62.7; on the following day, an 8-to-2 record at that intensity, and, on the 16th, also an 8-to-2 record. On January 31st, when he was again confronted with a variable light intensity of 87.8, he made an 8-to-2 record, immediately followed by a series with the variable intensity at 62.7, in which an almost

pure chance record, 6 to 4, was made. Since none of the other mice were able to make satisfactory records at the latter intensity, actual evidence of discrimination of that intensity from 40.84 can scarcely be considered afforded.

Three of the mice made records of 80 per cent or more correctness with the intensity of 87.8. Since, however, these good records are considerably interspersed with nearly or quite purely chance records, this intensity must apparently be regarded as very near the limen of discriminable difference. All but two of the mice made unquestionable records with the intensity of the variable light at 117. Nos. 27 and 299 seemed unable to give evidence of discrimination below an intensity of 198.6.

Aside from the records already cited of no. 291, attention may be called to the sharp break in discrimination displayed between two successive intensities by various individuals. For example, on February 2nd, no. 302, after a series in which an 8-to-2 record at the 87.8 intensity was made, was unable to make a satisfactory record when the intensity was cut to 62.7. More striking is the record of no. 300 on February 1st: a 9-to-1 record was made at the former intensity and six mistakes in ten trials when the intensity was cut to 62.7. On the succeeding day, this mouse made a pure chance record at the 87.8 intensity after a perfect record with the 117.

The results indicate that, with one possible exception, the best discrimination any of the mice were able to make as compared to an intensity of 40.84×10^{-6} C. cm.² was an intensity of 87.8×10^{-6} C. cm.²

DISCRIMINATION FROM A STANDARD INTENSITY OF 36.11×10^{-6} C. cm.²

Before these tests were begun, flashed-opal glass plates were substituted for the double-ground glass as stimulus patches in the 'ceilings' of compartments *C* and *C'*. The flashed-opal glass was subsequently found to transmit only about 13 per cent as great an intensity of light as did the double-ground glass. Hence, although the diaphragm opening used for the standard light in the present tests was

TABLE 4

Discrimination from a standard intensity of 36.11×10^{-6} C. cm.²

DATE	27		290		291		299		300		302	
1927	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
2/8	355.	8-2	355.	9-1	355.	9-1	355.	9-1	355.	9-1	355.	3-7
2/9	355.	10-0	355.	8-2	355.	10-0	355.	9-1	355.	10-0	355.	10-0
2/10	166.8	8-2			166.8	10-0	355.	8-2	166.8	7-3	166.8	10-0
2/11	166.8	9-1	355.	7-3p	91.5	8-2	355.	7-3	249.4	9-1	91.5	10-0
2/12	91.5	7-3	355.	10-0	91.5	10-0	355.	8-2	249.4	9-1	56.	5-5
2/14	91.5	6-4	166.8	8-2	66.	7-3	355.	7-3	249.4	9-1	91.5	6-4
2/15	166.8	10-0	166.8	9-1	76.9	7-3	355.	8-2	166.8	9-1	166.8	9-1
2/16	91.5	6-4p	91.5	8-2	76.9	6-4p	355.	9-1	91.5	8-2	91.5	7-3
2/17			91.5	9-1	91.5	9-1	166.8	8-2	91.5	8-2	114.	8-2
2/18	114.	8-2	76.9	6-4p	76.9	7-3	166.8	8-2	91.5	9-1	114.	7-3
2/19	114.	5-5	91.5	7-3	91.5	9-1	166.8	7-3	76.9	5-5p	166.8	9-1
2/19					76.9	7-3a						
2/21							355.	10-0	91.5	10-0	114.	10-0
2/21							166.8	7-3	76.9	8-2	91.5	5-5a
2/23	166.8	9-1	91.5	5-5p	91.5	6-4p	249.4	8-2	76.9	10-0	91.5	7-3
2/23	114.	10-0	166.8	5-5p			166.8	9-1	66.	9-1		
2/23	91.5	10-0					91.5	7-3p	56.	6-4		
2/23	76.9	4-6a										
2/26	91.5	6-4	166.8	8-2	91.5	10-0	166.8	6-4	76.9	9-1	114.	10-0
2/26			114.	8-2	76.9	8-2			66.	7-3	91.5	7-3
2/26			91.5	9-1	66.	6-4	166.8	9-1 ¹			114.	8-2 ¹
2/26			76.9	8-2			114.	7-3 ¹			91.5	10-0 ¹
2/26			66.	9-1			91.5	8-2 ¹			76.9	9-1 ¹
2/26			56.	7-3p			76.9	5-5 ¹			66.	8-2 ¹
2/26											56.	8-2 ¹
2/26											48.	5-5 ¹
2/26											56.	7-3 ¹
3/1	114.	10-0	76.9	7-3p	76.9	10-0			76.9	9-1	76.9	9-1
3/1	91.5	9-1			66.	6-4			66.	8-2	66.	9-1
3/1	76.9	8-2							56.	6-4p	56.	6-4
3/1	66.	8-2									56.	7-3a
3/1	56.	5-5									48.	6-4

¹ Given 2/28.

larger than for the tests just completed, the brightness of the stimulus patch was actually slightly less.

From the beginning of table 4, the fact will be noticed that the mice retained well from the previous set of tests the association of the avoidance of the dimmer of the two illumined patches with the escaping of the shock. In most cases the intensity of the variable light could be diminished with a good degree of rapidity. The best result obtainable at the conclusion of the period of training was the discrimination of an

intensity of 66 from the standard of 36.11. Nos. 27, 290, 300, and 302 were able to make satisfactory records with this intensity difference. On February 28th, no. 302 made an 8-to-2 record with the variable intensity at 56, dropping to a pure chance record when the intensity was reduced to 48 and making a 7-to-3 record when the intensity was returned to 56. On the next day this mouse was run, a 9-to-1 record with the 66 intensity was made, followed by failure in two consecutive series to make 80 per cent perfect records with the variable light at an intensity of 56. Since none of the other mice showed themselves able to make satisfactory records at this latter intensity, discrimination of it from 36.11 is exceedingly doubtful. The lowest intensity at which no. 299 made an 80 per cent perfect record was 91.5. The best accomplished by no. 291 was on March 1st, when a perfect record with the light at 76.9 was made, followed by a 6-to-4 record when the intensity was cut to 66. The sharp break in discrimination had been almost as clearly indicated at the same point on the day preceding.

The intensity of 66×10^{-6} C. cm.² is indicated by the present tests, therefore, to be just above the limen of discrimination for the mice from an intensity of 36.11×10^{-6} C. cm.²

DISCRIMINATION FROM A STANDARD INTENSITY OF 85.74×10^{-6} C. cm.²

As in the preceding set of tests, discrimination was in most instances good at the outset, so that the intensity of the variable light could be rather rapidly diminished. This effectiveness of the discriminatory response with change of absolute intensity is similar to the results of the experiments of Koehler with apes and chickens ('18). In the present case it is to be noted that the background was uniformly darkness, from which both plates stood out as a pair more definitely at any brightness than would have been the case in Koehler's experiments, where the background was evidently not controlled. For this reason, it is not unlikely that the transfer was more complete in the present instance.

TABLE 5

Discrimination from a standard intensity of 85.74×10^{-8} C. cm.²

DATE	27		290		291		299		300		302	
1927	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
3/3	609.7	9-1	609.7	6-4p	609.7	10-0	609.7	7-3a	609.7	9-1	609.7	9-1
3/4	609.7	8-2	609.7	8-2	355.	8-2	609.7	8-2	609.7	9-1	609.7	10-0
3/5	609.7	9-1	609.7	10-0	355.	10-0	609.7	7-3	609.7	9-1	355.	10-0
3/19	609.7	9-1	609.7	7-3p	609.7	10-0	609.7	10-0	609.7	10-0	609.7	10-0
3/21	609.7	8-2	609.7	9-1	355.	7-3p	355.	8-2	355.	7-3	355.	9-1
3/22	609.7	8-2	609.7	9-1	355.	9-1	355.	8-2	355.	10-0	355.	10-0
3/23	609.7	8-2	609.7	9-1	355.	9-1	355.	7-3p	249.4	7-3p	249.4	8-2
3/24	609.7	9-1	609.7	9-1	355.	10-0	355.	8-2	249.4	10-0	249.4	8-2
3/25	609.7	10-0	609.7	10-0	249.4	9-1	355.	8-2	166.8	8-2	249.4	10-0
3/26	355.	9-1	355.	5-5p	249.4	9-1	355.	10-0	166.8	7-3	166.8	9-1
3/28	355.	9-1	609.7	9-1	249.4	9-1	249.4	5-5	166.8	7-3p	166.8	7-3
3/29	249.4	9-1	355.	9-1	166.8	9-1	355.	9-1	249.4	9-1	166.8	8-2
3/29	166.8	7-3			128.2	5-5						
3/30	249.4	7-3p	355.	9-1	166.8	9-1	249.4	9-1	166.8	7-3	166.8	7-3p
3/30					128.2	5-5p						
3/31	249.4	8-2	249.4	7-3	166.8	9-1	249.4	8-2	166.8	8-2	166.8	10-0
3/31					128.2	7-3					128.2	5-5
3/31					128.2	7-3						
4/1			249.4	10-0	166.8	8-2	249.4	6-4p	166.8	9-1	166.8	10-0
4/1			166.8	9-1					128.2	5-5	128.2	4-6
4/1			128.2	6-4								
4/2			166.8	7-3	166.8	6-4p			166.8	8-2	143.	8-2
4/2			166.8	8-2					143.	4-6	128.2	6-4p
4/2			143.	4-6p							166.8	8-2

As table 5 indicates, nos. 290, 291, 300, and 302 made very good records, several of them perfect, when the intensity of the variable light had been reduced to 166.8. With a single exception, no satisfactory records for intensities lower than that were obtained. This exception occurred on April 2nd, when no. 302 made an 80 per cent perfect record with the intensity of the variable at 143. This result was duplicated by none of the other mice, however; no records of at least 80 per cent perfection were made with the variable intensity at 128.2. Attention is called to the records of no. 291 for March 29th, 30th, and 31st. On each of these days a sharp break in discrimination was manifested between the intensities of 166.8 and 128.2. The same is true for no. 302 on March 31st and April 1st; for no. 300 on April 1st and 2nd (the break occurred between 166.8 and 143 in the latter case,

TABLE 6
Discrimination from a standard intensity of 156.5×10^{-6} C. cm.²

DATE	27		290		291		299		300		302	
1927	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
5/2	609.7	6-4	609.7	7-3p	609.7	9-1	609.7	6-4	609.7	10-0	609.7	9-1
5/3	609.7	8-2	609.7	7-3	609.7	10-0	609.7	6-4p	355.	7-3	609.7	9-1
5/4	609.7	8-2	609.7	10-0	355.	7-3	609.7	5-5	355.	8-2	609.7	7-3
5/5	609.7	9-1	355.	8-2	355.	5-5	609.7	7-3p	355.	7-3p	609.7	9-1
5/6	609.7	10-0	355.	7-3	470.	8-2	609.7	9-1	470.	9-1	609.7	10-0
5/7	470.	5-5p	470.	6-4p	470.	9-1	609.7	7-3p	470.	7-3	470.	9-1
5/10	470.	9-1	470.	7-3p	470.	8-2	609.7	8-2	470.	10-0	470.	9-1
5/11	609.7	8-2	609.7	8-2	470.	7-3	609.7	6-4p	355.	6-4p	470.	9-1
5/13	470.	8-2	609.7	8-2	470.	10-0	609.7	8-2	470.	6-4	470.	10-0
5/14	609.7	8-2	609.7	9-1	355.	7-3p	609.7	7-3p	470.	9-1	355.	9-1
5/17	470.	6-4	609.7	8-2	355.	9-1	609.7	8-2	470.	9-1	355.	9-1
5/21	609.7	8-2	609.7	10-0	355.	7-3	609.7	8-2	470.	9-1	355.	7-3
5/23	609.7	9-1	470.	7-3	355.	5-5	609.7	9-1	470.	10-0	355.	10-0
5/23											249.4	4-6p
5/24	609.7	10-0	470.	8-2	470.	9-1	609.7	8-2	355.	9-1	355.	6-4p
5/26	470.	9-1	470.	9-1	470.	9-1	609.7	6-4	355.	6-4	355.	8-2
5/28	470.	9-1	470.	9-1	470.	9-1	609.7	5-5p	355.	8-2	355.	8-2
5/30	470.	6-4	470.	6-4p	355.	8-2	609.7	8-2	355.	5-5	355.	8-2
5/31	470.	7-3	609.7	10-0	355.	9-1	609.7	7-3p	470.	8-2	355.	7-3
6/7	470.	9-1	470.	5-5p	355.	8-2	609.7	7-3	470.	9-1	355.	8-2
6/8	470.	8-2	609.7	8-2	355.	9-1	609.7	7-3	470.	10-0	355.	8-2
6/10	470.	9-1			355.	9-1			355.	8-2	355.	9-1
6/10					305.	8-2			305.	6-4	305.	7-3
6/10					249.4	4-6						
6/11	470.	8-2			355.	5-5			355.	9-1	355.	8-2
6/11	355.	4-6							305.	7-3	305.	6-4
6/13					355.	8-2			355.	8-2	355.	8-2
6/13					305.	8-2			305.	6-4p	305.	9-1
6/13					249.4	6-4					249.4	8-2
6/13											249.4	6-4
6/14					355.	8-2			355.	10-0	305.	7-3
6/14					305.	4-6			305.	8-2	305.	8-2
6/14									249.4	5-5	249.4	6-4p

as was also true of no. 290 on the same day), and for no. 290 on April 1st. During the period of training nos. 27 and 299 were unable to make satisfactory records when the variable light was set at a lower intensity than 249.4.

The results indicate, therefore, that for most of the mice the limen of discrimination from an intensity of 85.74×10^{-6} C. cm.² lay close to an intensity of 166.8×10^{-6} C. cm.²

DISCRIMINATION FROM A STANDARD INTENSITY OF 156.5×10^{-6} C. cm.²

As table 6 indicates, learning in the cases of nos. 291, 300, and 302 was comparatively rapid. The other three mice

TABLE 7

Discrimination from a standard intensity of 493×10^{-8} C. cm.²

DATE	27		290		291		299		300		302	
1927	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.	Vari.	R. W.
6/15	1330.7	8-2	1330.7	7-3	1330.7	7-3	1330.7	9-1	1330.7	7-3	1330.7	9-1
6/16	1330.7	8-2	1330.7	9-1	1330.7	9-1	1330.7	6-4	1330.7	7-3	1330.7	8-2
6/17	1330.7	6-4	1330.7	6-4	1330.7	10-0	1330.7	6-4	1330.7	8-2	1330.7	10-0
6/18	1330.7	10-0	1330.7	6-4p	1060.6	9-1	1330.7	9-1	1330.7	7-3	1060.6	7-3
6/21	1060.6	7-3	1330.7	5-5	1031.3	8-2	1330.7	7-3	1330.7	9-1	1060.6	6-4
6/24	1060.6	6-4			1031.3	8-2			1060.6	9-1	1060.6	8-2
6/24					835.4	6-4			1031.3	10-0	1031.3	7-3
6/24									835.4	7-3		
6/25					1031.3	7-3			1031.3	8-2	1060.6	6-4p
6/25					1031.3	7-3			835.4	8-2		
6/25									716.6	4-6p		
6/27					1031.3	7-3			1031.3	6-4	1060.6	8-2
6/27					1031.3	7-3			1060.6	10-0	1031.3	10-0
6/27					1060.6	9-1			1031.3	8-2	835.4	4-6p
6/27					1031.3	9-1			835.4	7-3		
6/27					835.4	5-5p			835.4	9-1		
6/27									716.6	6-4		

failed to give good results, and work with them was consequently discontinued. Due to lack of time, this set of tests was somewhat curtailed, though tests were not discontinued before the least discriminable difference in intensity seemed clearly indicated. At the conclusion, an intensity of 305 could be distinguished from 156.5, while the intensity of 249.4 could not. The single exception to the latter statement is the 8-to-2 record made at the latter intensity on June 13th by no. 302. It will be noticed, also, that in several cases poor records were made with the 305 intensity, indicating apparently that the latter could be distinguished only with difficulty. In the cases of nos. 300 and 302, the records for the final four days seemingly indicate some improvement in ability to discriminate this intensity.

DISCRIMINATION FROM A STANDARD INTENSITY OF 493×10^{-8} C. cm.²

A few concluding tests were made with a greatly increased standard intensity; the data as given in table 7. Nos. 291, 300, and 302 again gave good results. Nos. 291 and 302 repeatedly made good records with an intensity of 1031.3, but

failed utterly to discriminate an intensity of 835.5. No. 300, on the other hand, on the two concluding days made 8-to-2 and 9-to-1 records, respectively, with the latter intensity. It will be noted that on the concluding day two series were given him at that intensity, with the result that a 7-to-3 record was made for the first, but a 9-to-1 record for the second. The evidence for discrimination of an intensity of 835.4 from 493 thus rests upon but slight foundation afforded by a single individual as opposed to the findings for two other individuals. The data for the latter indicate that an intensity of 835.4 was indistinguishable from one of 493, while an intensity of 1031.3 could be clearly distinguished.

BEHAVIOR DURING EXPERIMENTATION

The animals gave every evidence of good health throughout the course of the experiments. At no time during the tests were signs of excessive strain evidenced. Regardless of the severity of the discriminative conditions imposed, the mice did not fight against making their runs in the apparatus. Moreover, after the latter had become familiar to them, no special indications of fear or nervousness were manifested. The 'temperament' of the variety of deer-mouse used seemed to incline more toward pugnacity than fear and timidity. Since cage life was the only existence these mice had ever known, it is believed that the disadvantages of artificial surroundings were reduced to a minimum in their cases.

In the large majority of instances the mice would run directly from doorway 1 to compartment *C* or *C'*. After the problem had become well learned, this usually occurred without hesitation, the mouse apparently making his discrimination from doorway 1 or its vicinity. On the other hand, when a given animal did not have the association of dimmer light and shock well established, or when the discriminative problem became more exacting, hesitations were frequent. The mouse would run up to the entrances of *C* and *C'* and then run back and forth from one to the other, often several times, in an apparent effort to decide which was the correct path.

Finally, a 'decision' would be reached and the animal would run into one or the other of the compartments. In contrast to the others, no. 27 almost invariably made his runs at high speed. His discriminations seemed to be made from doorway 1, for he ran directly and rapidly into *C* and *C'* from that point, only occasionally altering his course as he approached *C* or *C'*. The fact that his initial training was received with lights of such greater intensity as to make such distant discrimination satisfactory may have thus modified his subsequent behavior in the apparatus. This peculiarity of behavior in no. 27 very likely accounts in large measure for the inferiority of the records he was, as a rule, able to make, though his eyesight may actually have been inferior to that of the others. His greater age will be recalled.

The experimenter could frequently tell by observation of the behavior of a mouse the point at which that mouse stopped discriminating much more clearly than the bare numerical record can indicate. One of the surest signs of inability to discriminate was the development by a well-trained individual of a position habit, i.e., a habit of going constantly to the right-hand or to the left-hand compartment regardless of how the lights were shifted. Such behavior was a certain indication that the mouse had 'given up.' In the tables only the most striking and undoubted cases of position habit and of alternation habit are indicated by the initials 'p' and 'a,' respectively. Position habits were easily formed—far more easily than were habits of responding solely upon the basis of visual stimuli. One of an experimenter's greatest tasks in a problem of this kind is that of overcoming the tendency to choose the route to be followed on the basis of position and to supplant this tendency with a habit of choosing the route on the basis of visual discrimination. This fact, emphasized again and again by the present experimentation, is perhaps suggestive of the relative importance in the lives of these animals of the kinaesthetic and of the visual elements.

CONCLUSIONS

The results of each set of tests are given in the discussion of the respective sets. The numerical results of the best records obtained are collected and summarized in the ac-

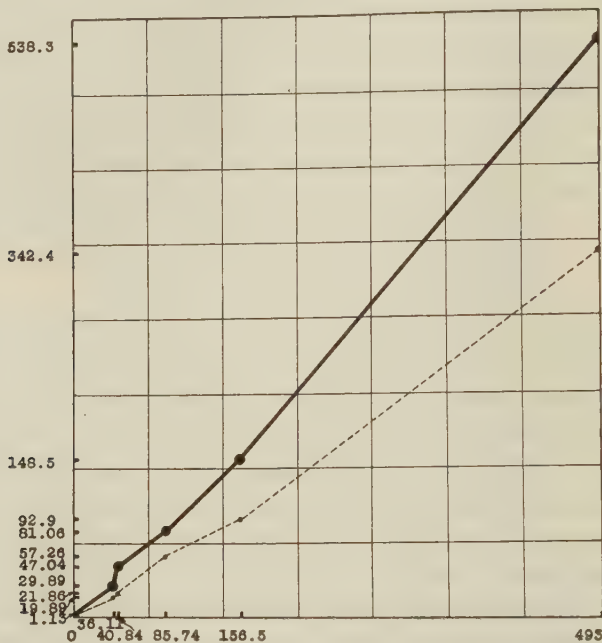


Fig. 5 Discriminable differences of intensity plotted against the five absolute intensities employed in the tests. Abscissa: brightness of the five standard intensities, in candles per $\text{cm}^2 \times 10^{-6}$. Ordinates: differences of intensity by which the variable light exceeded the standard to enable discrimination between them by the mice, in $\text{C. cm}^2 \times 10^{-6}$. The heavy line connects the well-established lower limits of discrimination noted in the preceding text. The dotted line forms the 'curve of possibility' in that the points on it represent isolated satisfactory records at intensity differences below the best well-established limits.

companying graph (fig. 5). It will be noted that, in general, the results indicate conformity to the Weber-Foechner law: the brighter the light the greater was the difference necessitated for discrimination. To a certain extent, also, the proportion borne to the intensity of the light by the difference required for discrimination was a constant. The per-

centages of the discriminable differences to their respective standard intensities are as follows, disregarding fractions of per cent: 36.11—83 per cent; 40.84—87 per cent; 85.74—94 per cent; 156.5—95 per cent; 493—109 per cent. The percentages for the five intensities are thus seen to be of the same general magnitude. The divergences from the expected constant are so small that attention might well not be called to them were it not for the fact that they are all in the same direction, i.e., progressive slight increases in percentage. Results are too meager to postulate any possible significance for this divergence from the results expected according to the Weber-Foehner law. It may be of interest to note, however, that somewhat comparable, slight, progressive deviations from the Bunsen-Roscoe law were recorded by Obreshkove ('21) for the photic reactions of tadpoles at certain intensities. Some of the results of Folger with amoeba are apparently indicative of the same sort of deviation from the constant expected under the Bunsen-Roscoe law, at least in the middle range of intensities employed ('25, table 5; multiplying 'luminous intensity' by 'reaction-time').

In common with other investigations on the discriminative ability of animals, the present tests have given abundant evidence of the long period of time over which improvement in discrimination may continue. Every effort was made to ascertain in each set of tests the least possible discriminable difference of intensity. Although the evidence of the attainment of the point of complete inability to discriminate has in each case seemed convincing, it would be folly to assert that in each instance the absolute limit was reached. It is believed, however, that at least the approximate limit was reached in each case. This view is upheld by the sharp break in discriminative ability between two successive intensities of the variable light, noted frequently in the preceding discussions. The magnitude of the total number of trials given the mice (a grand total for the six mice of over 12,000) would seem to insure that the association between shock and dim light would have maximum opportunity for firm implantation.

There are few results of other workers with which the present results can be compared. Yerkes ('07) trained one dancing mouse to discriminate between two lights, using the three standard values of 5, 20, and 80 hefners. The lights employed were thus much brighter than those used in the present work, one candle power equaling 1.2 hefners. Yerkes' tests indicated that a difference of one-tenth of the brighter light was sufficient to enable the dancer to distinguish between the lights. In the present work the difference of intensity required was found to amount roughly to one-half of the brighter (variable) intensity (in the case of the 'curve of possibility,' roughly one-third). Thus, the results do not correspond at all. The discrepancy may arise through actual difference in the ability of the animals used, differences in docility, or through differences in the technique, especially with regard to the absolute intensities of light employed in the two instances. Differences in the respective apparatus doubtless also played a part.

Spencer ('23) found white rats able to distinguish between the light passing through an episcotister disk opening of 21.8° from that through an opening of 5° , and similarly the light through an opening of 35.8° from that through one of 10° . That the above angular opening can be taken as indicative of the actual relative intensities employed does not seem certain, since mention is made of black-glass filters used to further reduce light intensities at times. If the angular openings actually did represent the relative intensities of the lights, however, the differences of intensity required for discrimination were, respectively, roughly four-fifths and two-thirds of the two respective standard or 'passive' (i.e., brighter) light intensities employed. It will be noted that the latter differences of intensity would be considerably larger than those found necessary for deer-mice in the present work.

Unfortunately, the numerical values of the various light intensities can give the reader but a limited idea of the lights themselves. In conclusion, the writer wishes to express his

opinion of the discriminative ability of the deer-mice as revealed by their work in the tests. Throughout the experimentation the slight actual differences which the mice were able to discriminate were a constant source of surprise. The mice at no time discriminated differences so small as to rival the ability of the writer's own eyes. Nevertheless, the query constantly recurred to him as to whether, if he were compelled to react solely on the basis of difference of intensity of two white stimulus patches in an apparatus as strange and unnatural to him as the apparatus employed in the present work must have been to the deer-mice, he would be able to make much, if any, better records or scores than did the latter.

MORPHOLOGY OF THE EYE

Gross anatomy

No detailed treatment of the structure of the deer-mouse eye is to be undertaken at this time, since the anatomy of the eye of *Peromyscus* is very similar to that of mice and rats in general. In these animals the eyeball is nearly spherical. The cornea and crystalline lens are large, the latter occupying a large portion of the volume of the eye (compare Reisinger, '15; Waugh, '10, fig. 9) and being nearly a complete sphere in shape. Since the retina is nearly equidistant from the surface of the lens throughout its extent, an arrangement for sharp focusing of rays of light entering the eye at very oblique angles would appear to be attained (Johnson, '01, pp. 64-65). Because of the relatively large size of the lens and its seemingly fixed focus upon the retina, accommodation for distance is probably, at best, slight, though objects within a limited range may be focused with a fair degree of sharpness. The same relation may give some amount of binocular vision without convergence of the eyes (Johnson, op.cit.; Waugh, '10, pp. 582-583).

Mice and rats have been found to possess neither an area of acute vision corresponding to the macula lutea in man nor a fovea (Chievitz, '91; Slonaker, '97; Waugh, '10). Johnson ('01) studied the eye of the black rat (*Rattus rattus*) oph-

thalmoscopically. No trace was found of an area wanting in blood vessels or having the latter reduced. Such an area in some other forms (rabbits, squirrels, many ungulates, and others) was interpreted as an especially sensitive region "which may have the function of a greatly extended macula."

As described by Reisinger ('15) for the albino rat, the ciliary process is but weakly developed, with reduced musculature. The iris, unlike that of the albino rat, is pigmented, but is nevertheless thin, with muscles apparently poorly developed. The sphincter muscle at the pupillary margin is by no means lacking, however.

Retinal histology

The principal interest for the present discussion lies in the study of the nature of the elements composing the visual-cell layer, i.e., the 'rods' and 'cones.' No study of the retina of *Peromyscus* has, apparently, before been made. Work has been done, however, on the retina of the house mouse and of the rat. Such studies have, for the most part, been incidental to investigation as to the absence of 'cones' from the retinae of nocturnal animals. Among the earlier workers there were differences of opinion concerning the visual elements in the retinae of rats and mice. Schultze ('66) found 'cones' lacking in mice, but possibly represented by rudiments in the rat. Krause ('76, '81, '95) denied the absence of 'cones' from the retina of the mouse, as well as from that of most other nocturnal animals. Grosskopff ('93) attempted to harmonize the two views on the basis of possible great similarity between 'rods' and 'cones.'

Yerkes ('07) reported but one type of retinal element in the dancing mouse: "rod-like cells, but nothing closely similar to the cones of the typical mammalian retina." Waugh ('10) studied sections of the retinae of gray, albino, and dancing mice, finding no evidence whatever of 'cones' in the visual-cell layer. Reisinger ('15) reported, concerning the retina of the albino rat: "Die Stäbchen- und Zapfenschicht ist ziemlich hoch, doch nicht differenziert; man kann die ein-

zernen Elemente nicht so klar unterscheiden, wie an der Netzhaut anderer Säuger." Detwiler ('24), working on the retina of an unidentified mouse from China, found no evidence of 'cones.' Keeler ('24, '26, '27) observed only 'rods' in the visual-cell layer of the albino house mouse.

Since the 'rods' in the visual-cell layer of the retina are usually considered the elements chiefly concerned with brightness vision, a study of the main features of the retinal histology of *Peromyscus* was thought pertinent to the present work. A portion of the retina is represented in cross-section in figure 6. The sections from which this drawing was made were cut 4μ thick and stained in Heidenhain's haematoxylin and Licht Grün. The point of particular interest for present consideration is the structure of the visual-cell layer. As will be seen from the drawing, 'rods' alone were found, there being no apparent traces of 'cones.' As 'cones' are the retinal elements usually considered as forming the basis of color vision, the mice may be expected to be color blind. Experimental evidence corroborative of this expectation has been obtained by Yerkes ('07) for the dancing mouse and by the Watsons ('13) for the albino rat. On the other hand, if strong development of the 'rods' may be assumed to be indicative of excellency in brightness vision, the eyes of *Peromyscus* and other mice would seem to be well equipped therefor. The 'rods' are long, slender, and tightly packed together. In correspondence to the multitude of 'rods,' the nuclei of the latter form an external nuclear layer of rather unusual thickness. Because of the slender, almost hair-like, appearance of the 'rods' under the microscope, but little of their structure could be ascertained. The external segments of the 'rods' present an appearance much like that shown in the drawing. Whether the cytological structure of these segments is in the form of lamellae or of a spiral (compare Oppel, '13, pp. 16-18) could not be made out with certainty, and the question is beyond the scope of the present work.

It will be noted that the outer segments of the 'rods' were stained by the haematoxylin, the inner segments remaining

nearly colorless. The condition usually described and figured for the retinae of most animals is just the reverse, the inner segments of the 'rods' staining with haematoxylin, the outer remaining uncolored (compare Cajal, '11). In order to test whether or not the condition noted above was peculiar to

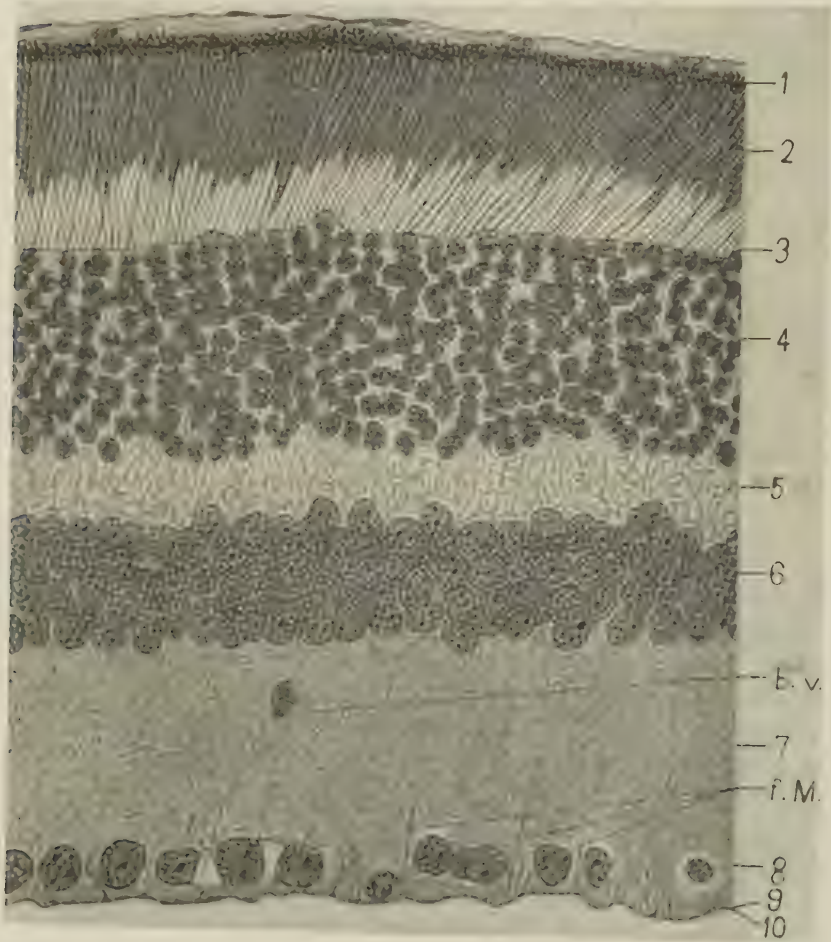


Fig. 6 Cross-section of a portion of the retina of *Peromyscus maniculatus gracilis*. ($\times 774$.) 1, pigmented epithelium; 2, visual-cell layer; 3, external limiting membrane; 4, external nuclear layer; 5, external reticular layer; 6, internal nuclear layer; 7, internal reticular layer; 8, ganglionic layer; 9, nerve fiber layer; 10, internal limiting membrane; *b.v.*, blood vessels; *f.M.*, fibers of Müller.

Peromyscus, the eye of a house mouse was sectioned and stained in the same manner. Here again the outer segments of the 'rods' were found stained with haematoxylin, the inner segments remaining clear. The explanation of the divergence of results obtained in this particular is, of course, unknown, but is apparently to be sought in differences between the stains or fixing agents used by the writer and those employed by many previous workers. In neither species did the outer segments of the 'rods' stain as deeply as did the nuclei. In general, the main retinal structures of *Peromyscus* and of the house mouse were found to be closely similar.

SUMMARY

1. Intensive training in discrimination between two white lights differing in intensity was given six deer-mice, *Peromyscus maniculatus gracilis* LeConte. The apparatus and technique employed are described.

2. The following six thresholds of light-intensity discrimination were found:

- a. From darkness 1.13×10^{-6} candle power per square centimeter of surface of the stimulus patch.
- b. From $36.11 (\times 10^{-6} \text{ C. cm.}^2)$: $66 (\times 10^{-6} \text{ C. cm.}^2)$.
- c. From $40.84 (\times 10^{-6} \text{ C. cm.}^2)$: $87.8 (\times 10^{-6} \text{ C. cm.}^2)$.
- d. From $85.74 (\times 10^{-6} \text{ C. cm.}^2)$: $166.8 (\times 10^{-6} \text{ C. cm.}^2)$.
- e. From $156.5 (\times 10^{-6} \text{ C. cm.}^2)$: $305. (\times 10^{-6} \text{ C. cm.}^2)$.
- f. From $493. (\times 10^{-6} \text{ C. cm.}^2)$: $1031.3 (\times 10^{-6} \text{ C. cm.}^2)$.

3. The above results were found to bear relationship to the Weber-Foehner law.

4. To in some degree correlate function with structure, the morphology of the eye and the retinal histology of the deer-mouse were studied. The visual-cell layer was found lacking 'cones,' whereas the 'rods' were found very highly developed—perhaps correlated with acuity of brightness vision. A histological drawing is given.

LITERATURE CITED

- CAJAL, RAMÓN Y 1911 *Histologie du système nerveux de l'homme et des vertébrés*. Paris: A. Maloine, 1909-11.
- CHIEVITZ, J. H. 1891 Ueber das Vorkommen der Area centralis retinae in den vier höheren Wirbelthierklassen. *Arch. f. Anat. u. Physiol., Anat. Abt.*, S. 311-334.
- DETWILER, S. R. 1924 Studies on the retina. Observations on the rods of nocturnal mammals. *Jour. Comp. Neur.*, vol. 37, pp. 481-489.
- FOLGER, H. T. 1925 A quantitative study of reactions to light in amoeba. *Jour. Exp. Zool.*, vol. 41, pp. 261-291.
- GAYTON, A. H. 1927 The discrimination of relative and absolute stimuli by albino rats. *Jour. Comp. Psych.*, vol. 7, pp. 93-105.
- GROSSKOPFF, W. 1893 Die Markstreifen in der Netzhaut des Kaninchens und des Hasen. *Anat. Hefte, Abt. 1, Bd. 2 (Heft 4)*, S. 1-25.
- HOGUE, M. A., AND R. J. STOCKING 1912 A note on the relative value of punishment and reward as motives. *Jour. Animal Behavior*, vol. 2, pp. 43-50.
- JOHNSON, G. LINDSAY 1901 Contributions to the comparative anatomy of the mammalian eye, chiefly based on ophthalmoscopic examination. *Phil. Trans. Roy. Soc., series B*, vol. 194, pp. 1-82.
- KEELER, C. E. 1924 The inheritance of a retinal abnormality in white mice. *Proc. Nat. Acad. Sci.*, vol. 10, pp. 329-333.
- 1926 On the occurrence in the house mouse of a mendelizing structural defect of the retina producing blindness. *Ibid.*, vol. 12, pp. 255-258.
- 1927 Rodless retina, an ophthalmic mutation in the house mouse, *Mus musculus*. *Jour. Exp. Zool.*, vol. 46, pp. 355-407.
- KOEHLER, W. 1918 Nachweis einfacher Strukturfunktionen beim Schimpansen und beim Haushuhn. *Abhandl. Berliner Akad. d. Wiss., Phys.-math. Klasse*, No. 2, S. 1-101.
- KRAUSE, W. 1876 Die Nerven-Endigung in der Retina. *Arch. f. mikr. Anat.*, Bd. 12, S. 742-790.
- 1881 Ueber die Retinazapfen nächtlicher Wirbeltiere. *Ibid.*, Bd. 19.
- 1895 Die Retina. VI. Die Retina der Säuger. *Internat. Monats-schr. f. Anat. u. Physiol.*, Bd. 12, S. 46-175.
- OBRESHKOVE, V. 1921 The photic reactions of tadpoles in relation to the Bunsen-Roscoe law. *Jour. Exp. Zool.*, vol. 34, pp. 235-279.
- OPPEL, A. 1913 *Lehrbuch der vergleichenden mikroskopischen Anatomie der Wirbeltiere*. 7ter Teil, Sehorgan. G. Fischer, Jena.
- REISINGER, L. 1915 Einige Eigentümlichkeiten des albinotischen Auges der weissen Ratte. *Zool. Anz.*, Bd. 46, S. 1-5.
- SCHULTZE, M. 1866 Zur Anatomie und Physiologie der Retina. *Arch. f. mikr. Anat.*, Bd. 2, S. 175-286.
- SLONAKER, J. R. 1897 A comparative study of the area of acute vision in vertebrates. *Jour. Morph.*, vol. 13, pp. 445-502.
- SPENCER, L. T. 1923 Central inhibition in the albino rat. *Jour. Comp. Psych.*, vol. 3, pp. 389-408.

- WARDEN, C. J., AND M. AYLESWORTH 1927 The relative value of reward and punishment in the formation of a visual discrimination habit in the white rat. *Jour. Comp. Psych.*, vol. 7, pp. 117-127.
- WATSON, J. B., AND M. I. WATSON 1913 A study of the responses of rodents to monochromatic light. *Jour. Animal Behavior*, vol. 3, pp. 1-14.
- WAUGH, K. T. 1910 The rôle of vision in the mental life of the mouse. *Jour. Comp. Neur. Psych.*, vol. 20, pp. 549-599.
- YERKES, R. M. 1907 The dancing mouse. The Macmillan Co., New York.

